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LCA COMMUNICATION AND LCA FOR ISO LABELS

Is the Eco-label EU Decision for hard coverings really capable of capturing the environmental performances of the marble productive chain? A field verification by means of a life cycle approach

Cinzia Capitano · Giorgia Peri · Gianfranco Rizzo

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Abstract
Purpose This work intends to show whether the Eco-label EU Decision for hard coverings, in which marble is contemplated among hard coverings as a natural product, is really capable of capturing the environmental performances of the marble productive chain, in other words whether it is actually viable for the natural products, like marble.
Methods After a preliminary critical analysis of the suitability for marble of the current EU Decision (2009/607/EC), a classical life cycle assessment (LCA) methodology has been applied on the field to the marble "Perlato di Sicilia." More specifically, the whole productive chain of a couple of firms treating the "Perlato di Sicilia" marble has been examined. The life cycle analysis is actually a cradle-to-gate analysis which includes the raw material extraction, processing phase, and finishing operations.
Results and discussion Both the preliminary critical analyses of the structure of the Decision and the in-field checking on the two firms of the Custonaci marble district in Sicily singled out several conflicting points of the Decision for the marble working chain. These difficulties could be reasonably extended to other natural stones, such as granite, for which similar working processes are applied.

Based on the outcomes of both these analyses, in the present work, a set of new indicators and modified criteria, already present in the Decision, is proposed as a candidate to be considered for inclusion in a future release of the Decision.
Conclusions The changes here introduced can represent a useful indication toward a more suitable scheme of the EU Eco-label for marble, at least. Clearly, further investigations need to better assess the proposed scheme, especially in terms of threshold values of pollutant releases and use of explosive that are actually specific for the marble productive chain. The present modified version of the standard has been proposed to the Sicilian administration in order to be voluntarily adopted by marble productive sites of the region, in the aim of extensively verifying its suitability.

Keywords EU Eco-label Decision · Hard coverings · LCA · Marble productive chain · Natural products

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C. Capitano (✉) · G. Peri · G. Rizzo
Department of DEIM, University of Palermo, Viale delle Scienze, Building 9, 90128 Palermo, Italy
e-mail: cinzia.capitano@dream.unipa.it

1 Introduction

As it is well known, the building sector represents one of the most important elements in the economy of the developed countries, accounting for approximately 40 % of the whole energy consumption, being responsible of a large amount of pollutant releases in the atmosphere and requiring a significant part of resource consumption (IEA 2008).

In addition, the quarry-related activities of material typically used in buildings are characterized by a high environmental impact and by a severe footprint on the territory (Gazi et al. 2012; Nicoletti et al. 2002). Similarly, operations involved in the production of marble cause a high impact on the involved territory (Traverso et al. 2010).

In Sicily, for example, the diffuse presence of marble quarries and manufacturing plants is raising a big concern about the environmental compatibility of such plants. In Fig. 1, all of the quarries present in the Sicilian Region are shown, as they are spread in the territory, including the marble ones; currently, there exist 557 quarries in operation and 691 worn-out quarries (Legambiente 2011).

By another point of view, it must be noted that building materials, within a general approach aimed at the improvement

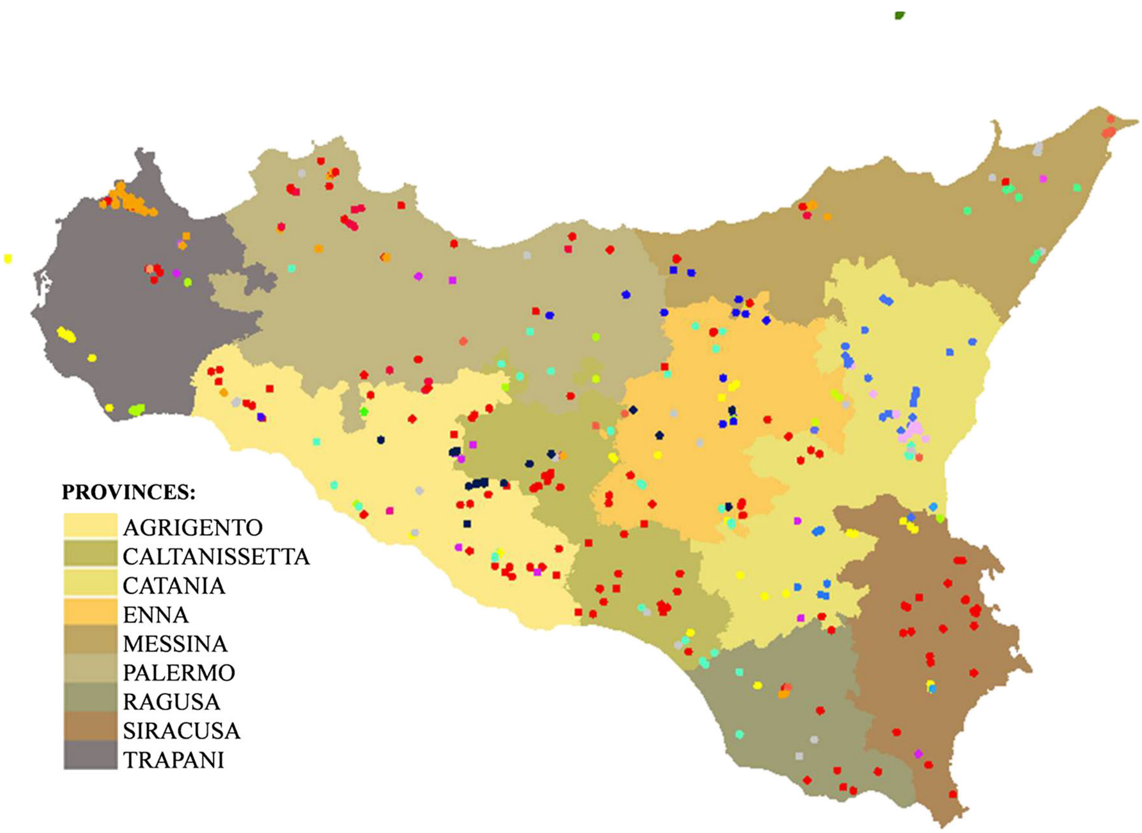


Fig. 1 Distribution of the quarries in operation in Sicily

of the energy efficiency of this sector (Franzitta et al. 2011), are increasingly called to achieve quality brands that, generally, aim at the energy and environmental certification of such materials (Peri and Rizzo 2012).

Within the European scheme for awarding building products with the Eco-label (Regulation EC no. 66/2010) brand, marble is contemplated among hard coverings, as a "natural product." In fact, the European Commission Decision 607 of 9 July 2009, establishing ecological criteria for awarding hard coverings by the Community Eco-label, subdivided these products into two major groups: "natural products" and "processed products." "Natural products" are materials existing in the environment which include marble, granite, and other stones that can be found in nature. Whereas, the group "processed products" can be further divided into two subgroups, that are "hardened" and "cooked" products. The first ones are agglomerated stones, like concrete blocks and terraces, while the latter are ceramic tiles and bricks (European Commission 2009). According to this classification, marble belongs to the class of natural products.

The analysis of the marble manufacture, as well any other marble productive chain, might be usefully conducted by dividing the whole process into three main phases:

- Raw material extraction in quarry (generally, "open sky" sites)
- Marble processing in sawmill
- Finishing operations in laboratory

Figure 2 outlines the typical operations occurring in quarry, sawmill, and laboratory for the Sicilian marble "Perlato di Sicilia" productive chain, along with the indication of main input and output of each working phase, in terms of energy, materials, and by-products flows involved in the operations. Squared, semi-squared, and shapeless blocks are the main output of this typical marble mining process. Afterward, such blocks are sent to the sawmill for further manufacturing activities, particularly, the cutting operations. The output materials of this further working phase are then sent to a laboratory, to be polished and (in case) resin tipped.

In sight of the identification of the firms eligible for an Eco-label award, a preliminary verification of the EU Decision 2009/607/CE, in terms of their environmental performances should be conducted, in order to verify the full compatibility of criteria present in the Decision with impacts associated to the working chain of marble. On the basis of this preliminary analysis of the structure and criteria of the Decision referring to the phases of a working chain belonging to the marble district in Sicily, certain limitations of the Decision in catching all impacts exerted by this productive chain seem to arise.

Furthermore, these limitations are checked by means of an "in the field" application of a classical LCA methodology to a firm belonging to the marble Custonaci basin, where they seem to be confirmed.

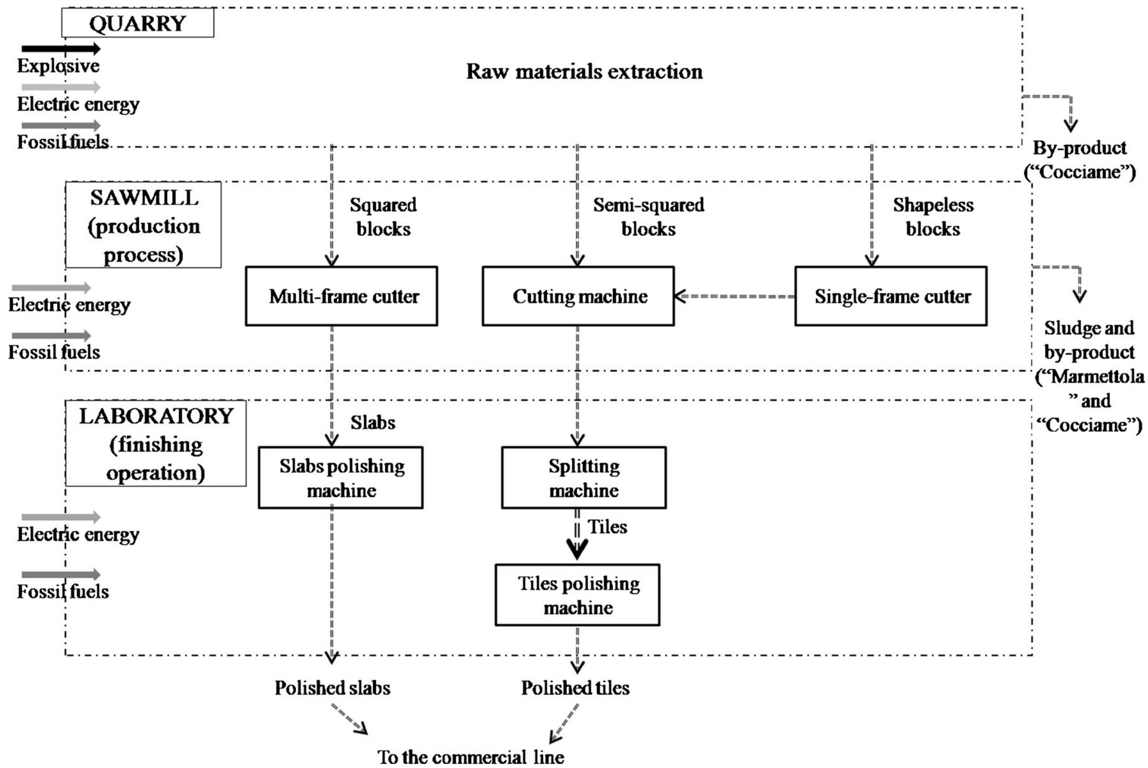


Fig. 2 Diagram of the manufacturing process of the "Perlato di Sicilia" marble, highlighting the main operations carried out in quarry, sawmill, and laboratory, with indication of the involved energy and material flows

The assessment of the environmental and energy impacts caused by 1 m^3 of Sicilian marble is a largely treated issue in literature (Capitano et al. 2011; Traverso et al. 2010; Traverso et al. 2012; Valdivia et al. 2013). Clearly, there exist many LCA studies referring to the marble sector. Among these, for example, Liguori et al. (2008) analyzed impacts caused by 1 m^3 of Carrara marble; Gazi et al.(2012) studied the impact generated by 1 m^2 of "Greek marble" and compared the obtained results with those obtained by Traverso et al. (2010) and Nicoletti et al. (2002). The latter (Nicoletti et al. 2002), in fact, has applied a life cycle assessment to compare two covering materials produced in Italy, i.e., marble and ceramic tiles, to identify the best one from an environmental point of view. Furthermore, Careddu and Siotto (2011) analyzed the main environmental impact factors (noise, vibrations, fumes, dust, vehicle traffic) associated to the marble quarries and the manufacturing industry in the Orosei (Sardinia) area, proposing suggestions to prevent, reduce, and, where possible, delete the impact on the environment.

Even though there exist many LCA studies referred to marble, to the best of our knowledge, no research work is currently available in scientific literature on this particular topic (Eco-label criteria), apart the work carried out by Baldo et al. (2002), which consisted using LCA to develop Eco-label criteria for hard floor coverings whose results have been then published in the EU Decision 272/2002 (European Commission 2002), which represent the previous version of the Decision 607/2009 here analyzed.

2 Analyzing the European Commission Decision 607/2009 with respect to a typical marble working chain

Criteria contained in the EU Decision 2009/607/CE for the EU Eco-label of hard coverings are here analyzed, in order to check their applicability to marble and natural stones, in general.

The EU Eco-label we are referring to is the European brand (Regulation EC n. 66/2010) assigned to the products and services which are characterized by high environmental performance over their entire life cycle. The EU Eco-label brand is defined in the ISO 14020 (2002) as an ISO type I label (ISO 14024, 2001) by definition is a third party certification. These labels are based on a multi-criteria scheme where each criterion sets precise benchmarks that need to be fulfilled to be awarded with this brand by an impartial third party. It is a strong communication tool by means of which such products/services can be quickly and easily recognized by the market that requires products characterized by higher and higher performance standards.

The European Commission Decision 607 of 2009 establishes the ecological criteria for awarding hard coverings by the Community Eco-label.

A schematic description of the Decision is reported in Table 1 where, for each criterion, provided its identification number, its object, the class of products to which the criterion refers, the sub-criteria of which each criterion is composed, and the pertinent working phase.

Table 1 Schematic description of the Decision Commission 607/2009/EC (European Commission 2009)

Criterion no.	Object	Class of products	Sub-criterion	Pertinent working phase
1	**Raw material extraction**	Natural products All hard covering products	**1.1. Extraction management (a)** 1.2. Extraction management	Quarry
2	**Raw materials selection**	All hard coverings products	**2.1. Absence of risk phrases in raw materials**	Quarry
		Glazed tiles	2.2. Limitation of the presence of some substances in the additives	–
		All hard coverings products	**2.3. Limitation of the presence of asbestos and polyester resins in the materials**	Quarry
3	**Finishing operations**	Natural products	–	Laboratory
4	Production process	Processed products Processed products	4.1. Energy consumption 4.2. Water consumption and use	–
		Processed products	4.3. Emissions to air	
		Processed products	4.4. Emissions to water	
		Processed products	4.5. Cement	
5	**Waste management**	Natural products	**5.1 Waste management**	Quarry and laboratory
		Processed products	5.2. Recovery of waste	–
6	Use phase	Glazed tiles	6.1. Release of dangerous substances	–
7	Packaging	–	–	–
8	Fitness for use	–	–	–
9	Consumer information	–	–	–
10	Information appearing on the Eco-label	All (natural and processed) products	–	–

Note: criteria reported in bold are those analyzed in the present work

Six main indicators are here identified: *I1* water recycling ratio, *I2* quarry impact ratio, *I3* natural resource waste, *I4* air quality, *I5* water quality, *I6* noise

Criteria in the range 6 to 10 are not included in the present analysis, since the corresponding phases do not apply to the productive site but belong to external segments of the productive chain. As that, the following criteria from 1 to 5 of the Decision are analyzed with respect to the abovementioned productive chain of the "Perlato di Sicilia," which are extraction in quarry, processing in sawmill, and finishing operation in laboratory. In Table 1 criteria referring to natural stones that will be analyzed in the present work are those reported in bold.

In more details, criteria 1, 2, and 5 (that is "raw material extraction", "raw materials selection", and "waste management", respectively) referring to the extraction phase in quarry (see the last column of the Table 1), will be discussed in the Sect. 2.1. The manufacturing process of slabs and tiles in sawmill will be discussed in Sect. 2.2. Whereas, criteria 3 and 5 (that is "finishing operation" and "waste management") referring to the finishing operations in laboratory (see the last column of the Table 1) will be treated in Sect. 2.3.

2.1 Analysis of criteria for quarry operations

In this section criteria referring to typical operations occurring in marble quarries are analyzed. They involve criterion 1 ("raw material extraction"), criterion 2 ("raw materials selection"), and criterion 5 ("waste management").

Criterion 1 Raw material extraction.

The Decision assumes that raw material extraction management for natural stones shall be evaluated using a matrix of six main indicators, that are I1, "water recycling ratio"; I2, "quarry impact ratio"; I3, "natural resource waste"; I4, "air quality"; I5, "water quality"; and I6, "noise." The raw material extraction management shall be scored according to a matrix of these indicators. The main features of each of the six indicators are shortly reported in the following.

I1 Water recycling ratio.

This indicator is calculated as the ratio between the *waste water recycled* and the *total water that exits the process* (every active quarry must ensure, in fact, a proper supply). For waste water is here meant only as water used in processing plants, not comprehensive of the fresh water coming from rain and subsoil water. The related calculation algorithm is in the following form:

$$\frac{\text{m}^3\text{of waste water recycled}}{\text{m}^3\text{of total water leaving the process}}[\%].$$

I2 Quarry impact ratio.

Its calculation is based on the measurement of both affected (which includes quarry front and active dump areas) and the authorized areas. Then, the calculation algorithm is the following form:

$$\frac{\mathrm{m}^2\text{of affected area (quarry front} + \text{active dump)}}{\mathrm{m}^2\text{of authorised area}}[\%].$$

I3 Natural resource waste.

This indicator is calculated as the ratio between the usable material and the total volume extracted yearly. Usable material refers to the whole volume which can be used in any process: for the case of marble, commercial blocks, aggregate materials, and everything else suitable for further processing and use. The pertinent calculation algorithm is in the following form:

$$\frac{\mathrm{m}^3\text{ usable material}}{\mathrm{m}^3\text{extracted material}}[\%].$$

I4 Air quality.

According to the Decision, the calculation consists of the measurement, along the border of the quarry area, of PM_{10} suspended particles based on specific requirements of the general provisions of Directive 1999/30/EC (Council Directive 1999) and of the test method defined in UNI EN 12341 (2001).

I5 Water quality.

This indicator considers the total emissions of suspended solids occurring after surface water treatment flowing out of the mine site. To calculate this indicator, the measurement of total suspended solids (mg/l) using the test method reported in ISO 5667-17 (2000) is needed.

I6 Noise.

This indicator considers the noise level (on impulsive noises) recorded along the border of the quarry area. To calculate the I6 value, the measurement of the noise [dB(A)] using the test method reported in ISO 1996-1 (2005) is needed.

To be eligible for the EU Eco-label, mines must obtain a weighted score of at least 19 points over the six indicators. In addition, the score of each indicator must be higher or lower than a threshold specified as appropriate (European Commission 2009). The total score achieved, within the Decision's scheme, shall be based on the sum of individual scores given for each indicator, multiplied by its corrective weighting (W). The values of these weighting factors are indicated in the EU Decision depending on three different categories, that are the soil use class (W1), the density of settlements (W2), and the interference with surface water bodies (W3).

Anyway, for the application to the marble working chain, the above indicators need to be further discussed.

With reference to indicator I4 ("air quality"), it must be observed that apparently it is not exhaustive enough for marble because it only requires to calculate PM_{10}, in this way neglecting all other pollutant emissions which, actually, occur in a marble quarry. In fact, use of electricity and consumption of fossil fuels (typically, diesel oil), which are involved in the extraction activities, also lead to the release of gaseous pollutants into the atmosphere such as NO_x, SO_2, CO, and CO_2, that are recognized as important causes of the worsening of the environmental quality (IPCC 2007) Therefore, it would be important that the regulation for the EU Eco-label for hard coverings would also account for these emissions and would set threshold values, not only for PM_{10} but also for these other pollutant components.

Another important point to be further considered is given by a fundamental field analysis (Legambiente Carrara 2007) provided by an Italian environmental institution, that signals in the marble district of Carrara the presence of $PM_{2.5}$ (fine suspended particulate); actually, the analysis revealed that as far as 93 % of the fine particulate in the area is represented by $PM_{2.5}$, while in the Italian towns account for 50 % of the whole particulate matters. Moreover, high percentages of breathing diseases have been noticed among inhabitants of Carrara; these values are surprisingly not in line with the national average values (Legambiente Carrara 2008). This fine particulate is capable to penetrate deeply into lungs during breathing and, despite the detailed mechanism with which it interferes with body's organisms, is not completely clear yet; it is known that the smaller the size is, the highest the possibility of biologic interaction is. Among the main problems caused by fine and ultrafine particulates (PM_{10} and, especially, $PM_{2.5}$), acute and chronic pathologies involving both the breathing system (asthma, bronchitis, emphysema, allergy, tumors), and cardiovascular system in predisposed subjects must be contemplated (Dominici et al. 2006; Donaldson and Mac Nee 2001).

Based on the above considerations, the indicator "air quality" would need to be modified, aimed to account for all pollutant emissions in atmosphere caused by the marble production activities.

As far, the possible introduction of new indicators is in question for marble, a parameter accounting for the amount of blocks extracted and sent to the sawmill with respect to the total amount of material extracted, should be also introduced. Actually, such an indicator was already present in the above cited first version of the Decision (European Commission 2002); but, it was then deleted in the version now in use.

Moreover, an indicator that quantifies the relevant volume of materials disposed in landfills should be further introduced, since it appears indispensable for a comprehensive assessment of the environmental performances of the product.

Another indicator, able to take into account the use of explosive in quarry, should be added as well. In fact, explosives are often used in marble quarries to remove the vegetation layer below which the raw material is placed. Problems caused by the use of explosive are different: both the environmental impacts generated by the use of this energy source and the potential consequences on workers (the safety levels in working places) must be considered. Therefore, an analysis about the type of explosive utilized and about its effect on the environment and people is recommended (Mancini and Cardu 1997). Type and quantities of explosives used must be therefore defined with respect to the amount of materials removed (m^3).

The possible introduction of such new indicators will be described in more detail in Sect. 4.

Criterion 2 Raw materials selection.

The Eco-label regulation establishes that raw materials must not contain substances or preparations that are assigned in any of the 18 risk phrases reported in the same Decision (e.g., substances with risk code R45, which may cause cancer are not allowed). Moreover, it states that either raw materials used for natural products cannot contain asbestos or the use of polyester resins in production is limited to 10 % of the total weight of raw materials.

These requisites confirm the full suitability of criterion 2 and also for marble.

Criterion 5 Waste management.

The Decision establishes that the waste derived from quarrying should be properly treated. Particularly, in sub-criterion 5.1 (“waste management”), it refers to the extraction and polishing operations, while all the cutting procedures occurring in sawmill are neglected. Moreover, no criteria accounting for the recovery and/or reuse of waste are present, despite the extraction phase of marble is characterized by a significant recovery of waste material. These materials are mainly constituted of marble blocks of various sizes, that can be usefully recovered and commercialized (Akbulut and Gürer 2007; Hebhoub et al. 2011). As that, this criterion seems to be applicable to marble with some modifications, as discussed in Sect. 4.

2.2 Analysis of criteria for sawmill operations

In the Decision for the EU Eco-label for hard coverings, no criteria accounting for the whole production process of marble blocks in sawmill (Fig. 2) are contemplated. Actually, this represents an important weakness in the Decision, since plant cutting operations, typically occurring in sawmill, are significantly energy-consuming (Gazi et al. 2012).

Manufacturing processes of marble such as cutting to suitable sizes and polishing for ornamental purposes produce marble dust, and aggregate as by-products. In fact, during the cutting process, 20–30 % of the marble blocks turn into dust (Gencel et al. 2012).

Unfortunately, as previously noticed, in the Decision, there are no criteria referred to the manufacturing process of marble slabs and tiles in sawmill. Therefore, the Decision seemly does not take into account neither energy and resources consumption nor air and water pollutant emissions that occur in this phase. This lack does not allow to suitably evaluate the impacts caused by the production process of marble.

Moreover, criterion 5, concerning the waste management, simply refers to the management of waste derived from quarrying and finishing operations, in this way totally neglecting the waste from processing operations (occurring in sawmill). Actually, the production of marble slabs and tiles results in a significant amount of sludge and by-product.

In addition, also in this case, as noticed for quarry, the waste recovery is not considered, although the sawing sludge could also be used for environmental recovery of worn-out quarries (D’Agostino et al. 2006; D.lgs. 152 2006).

Based on these considerations, the inclusion of a new criterion that accounts for the all impacts caused by the production process of marble is suggested here, as will be introduced and discussed in Sect. 4.

2.3 Analysis of criteria for finishing operations in laboratory

In this section, criteria referred to the finishing operations occurring in laboratory (Fig. 2) are analyzed. These are criteria 3 (“finishing operations”) and 5 (“waste management”).

Criterion 3 Finishing operations.

In case of marble, finishing operations consist of polishing and (possible) resin tapping of finished products.

The Decision requires to measure particulate emission into air (PM_{10} and styrene), water recycling ratio, and emission into water (suspended solid, Cd, Cr(VI), Fe, and Pb). However, this criterion, although accounting for the environmental impacts generated by finishing operations (mostly emissions in water), does not consider the energy consumption due to the different equipments utilized in this phase.

A proposed modification of this criterion will be introduced and discussed in Sect. 4.

Criterion 5 Waste management.

The Decision establishes that the waste derived from finishing operations should be properly treated. As that, it is fully pertinent to marble.

3 Field verification of the suitability to marble of EU Decision 2009/607/EC by means of a life cycle analysis approach

As observed earlier, some criticisms have been found during the checking of the suitability of the Decision to the working chain of marble. Clearly, an "on the field" verification of the manufacturing process of the marble, from both energy and environmental perspectives, would be useful to confirm or not this preliminary analysis. On purpose, a life cycle evaluation of a firm belonging to the Custonaci basin (Trapani, Sicily) is here reported (for privacy reasons, the firm under analysis is simply called "firm A").

The Life Cycle Assessment (LCA) methodology, as it is well known, is able to evaluate the (potential) impacts on the environment of a product/service along its entire life cycle (Heiskanen 1999; Klöpffer 2008). It is a well-known approach with a standardized procedure (ISO 14040 2006; ISO 14044 2006) which consists of the following steps: goal and scope definition, inventory analysis, impact assessment, and results interpretation.

By applying the LCA to the manufacturing plant of marble slabs and marble tiles of "Perlato di Sicilia," a "cradle-to-gate" approach was applied to the product life cycle, instead of the "cradle-to-grave" one (Klöpffer 2003; Pieragostini et al. 2012). Clearly, we are aware that for an Eco-label of marble, a complete LCA would be more appropriate (from "cradle-to-grave"); however, it is true that the segment regarding the life cycle from the "gate-to-grave" (that includes the use and disposal phases) is generally affected by uncertainties; in fact, the impact of the use phase is related to the washing activity and possible surface finishing; whereas, the disposal phase is timely (due to the generally long duration of this product) and geographically (due to the fact that marble is produced in a relatively few sites while it is exported all over the world, making a particularly complex operation the gathering of these data) far away from the manufacturing site.

In other words, the two different phases show a quite different reliability for marble. Therefore, the inclusion of these two phases within the LCA could negatively influence the Eco-label criteria.

As a result, we propose here to extend the analysis up to the gate, in this, also supported by the product category rules (PCRs) of marble, where it is not an accident that these two phases are omitted (Product category rules (PCR) 2010). PCRs are, in fact, product-specific calculations and requirements that have been released to help the preparation of an environmental product declaration (EPD) of a product based on the results of an LCA (Zackrisson et al. 2008; Strazza et al. 2010; Srdić and Šelih 2011). As that, we suggest a simplification of the LCA scheme for marble to establish an Eco-label.

In the following, the study carried out is briefly described, by illustrating its main features and by defining the involved components.

Functional Unit The selected functional unit (FU), here considered, was 1 m^3 of marble at the gate of the manufacturing plant. This choice arises from the consideration that the extraction of marble clearly requires to refer to a volume rather than a surface of the treated material. Throughout the working chain of marble here considered, we have chosen to maintain the same volume-based functional unit, instead of changing it during the LCA application. Clearly, 1 m^3 of treated marble can be usefully converted into 1 m^2 of covering (corresponding to the use of the product), by simply dividing the height of the marble cube by the mean thickness of a tile (3 cm, typically).

System boundaries Concerning the system boundaries for the application, as mentioned earlier, we assessed a partial product life cycle (a "cradle-to-gate" segment instead of the "cradle-to-grave" one). The following productive phases were then considered:

- Raw material extraction (*cradle*). Activities involved in this phase include cutting the rock into chunks using mechanical means, to tip them onto the quarry area, to square them into blocks according to commercial sizes, and to transport (using mechanical means) these blocks to the storage areas and the waste produced to apposite landfills. The primary energy sources used in quarry are diesel oil (that serves to move the necessary equipment within the quarry area and to transport the blocks into the storage areas), explosive (necessary to remove the surface vegetative layer below which there is the raw material), and water and electric power (see Fig. 3).
- Cutting and polishing of finishing products along with the transportation operations occurring within the plant (*factory's gate*). The process begins with the *sawing* of

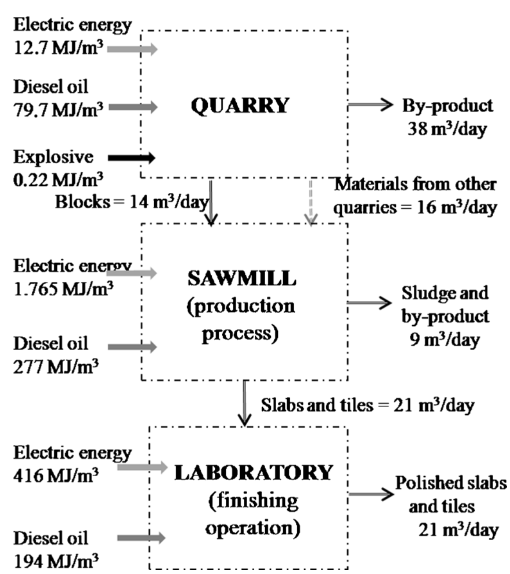


Fig. 3 Specific (MJ/m^3) energy amount involved in the manufacturing process of "Perlato di Sicilia", subdivided by quarry, sawmill, and laboratory

stones into either great size “slabs” or “tiles.” The slabs are obtained from squared blocks, using “multi-blade” frame. While the tiles are obtained from semi-squared blocks of smaller dimensions (called “shapeless”) that are sawn by a machinery with two circular diamond discs (saws): one that cuts vertically and the other one horizontally (each cut corresponds to a tile).

Finishing is a dry operation carried out manually to correct any imperfections present on the slab/tile (edges, corners, coasts) or on the whole surface.

Polishing is the last process. Appropriate electric tools are used and a certain amount of water is constantly provided over the process to polish properly abrasive wheels utilized.

Likewise, the involved sources of energy are oil, electric energy, while water is the most important used resource (see Fig. 3).

Assumptions Certain assumptions have been taken during this LCA analysis that are the following:

- The transportation of scrap and spoil to the landfill is included in the system boundaries.
- All scraps from quarry and sawmills are discarded in a dedicated landfill.
- The water used for cooling the diamond wires and saws in the quarry is not recycled.
- The water used in the sawmill is recycled, so causing a production of sawing sludge.
- Although the sawing sludge disposal could be used for environmental recovery of worn-out quarries (D.lgs. 152 2006), this is not considered in this work (D’Agostino et al. 2006).

Inventory analysis As regards the inventory, primary data were obtained by directly contacting the management of the considered firm.

Impact assessment The impact assessment has been effected by using the characterization factors contained in the CML-IA database (CML-IA 2012) and in the SimaPro© database (SimaPro 2012). The selection of two different databases is justified by the various assumptions to which each of them refers (Plassmann et al. 2010), in this way approaching in a more complete way the singling out of the environmental impacts.

The amount of the energy required to produce 1 m^3 of marble (Liguori et al. 2008) at the factory’s gate was then calculated and split in three main components: the energy in quarry, in sawmill, and in the laboratory, respectively, as reported in Fig. 3 where typical values of the daily treated materials are also reported.

The related pollutant emissions per functional unit occurring in quarry, sawmill, and laboratory were calculated by cumulating the emissions caused by the use of each single energy source (electric energy and diesel oil) and explosive used in the different phases of the productive chain (Table 2) during the whole life cycle. For indirectly computing these emissions, the proper emission factors of the energy sources were applied (Table 3).

The resulting potential impact of 1 m^3 of marble produced in the examined firm was 486 kg_{CO2eq} of global warming (GWP), 1.83 kg_{SO2eq} of acidification (AP), 0.11 kg_{PO4eq} of Eutrophication (EP), 1.86 $kg_{1.4\text{-dichloroben.eq}}$ of human toxicity (HTP), and 0.07 $kg_{\text{ethylene eq}}$ of photochemical oxidation (POCP).

This LCA application to the working operations occurring in a typical marble firm of the Sicilian productive district does confirm the criticisms that the preliminary analyses of the Decision 607/2009 have arisen. In fact, the “on the field” checking of this marble productive site singled out the

Table 2 Pollutant emissions (g/m^3) per functional unit related to the consumption of the involved energy sources and explosive, in quarry, sawmill, and laboratory

	Quarry			Sawmill		Laboratory	
	Electric energy	Diesel oil	Explosive	Electric energy	Diesel oil	Electric energy	Diesel oil
CO_2	2,547	5,901	23.73	354,035	20,483	83,385	14,372
NO_x	2.54	63.08	0.00	353.03	218.96	83.15	153.63
SO_2	6.60	1.83	7.67	916.91	6.37	215.96	4.47
CO	2.47	15.65	5.04	343.23	54.31	80.84	38.11
HC	0.02	0.16	–	3.00	0.55	0.71	0.39
PM_{10}	4.78	4.69	–	664.39	16.28	156.48	11.42
SOV	–	16.78	–	–	58.26	–	40.88
K_2O	–	–	16.43	–	–	–	–
K_2S	–	–	12.85	–	–	–	–
$PM_{2.5}$	–	4.22	–	–	14.64	–	10.27

Table 3 Emission factors (g/MJ) for electric energy, diesel oil, and explosive (Ministero delle Attività Produttive 2002)

Emission factors	CO_2	NO_x	SO_2	CO	HC	PM_{10}	SOV	K_2O	K_2S	$PM_{2.5}$
Electric energy	200.5	0.2	0.52	0.19	0.002	0.38	–	–	–	–
Diesel oil	74	0.79	0.02	0.20	0.002	0.06	0.21	–	–	0.0529
Explosive	108.33	–	35	23	–	–	–	75	58.67	–

involvement of pollutant emissions and the release of fine particulate (with a radius <2.5 μm) in quarry, that was not taken into account in the criteria of the Decision. Furthermore, the sawmill operations involve a large amount of energy and, in turn, of pollutant emissions that are not considered in the current version of the Decision. Moreover, the sludge and scrap production of sawmill are not considered as well. Finally, the energy consumption involved in the finishing operations of marble is omitted in the present Decision structure.

4 Discussion and proposals

From the preceding analysis and considerations, the need for a revision of the European Decision actually in force for hard coverings has arisen, in order to render it more suitable for marble and for natural stones that show a working chain similar to the marble.

4.1 Criterion 1—Raw material extraction

In the current release of the Decision, *criterion 1* (“raw material extraction”) is composed of six indicators. Anyway, in order to better evaluate the environmental performances of productive chains of marble, possible new indicators should be included in the Decision’s structure, while some of the existing ones should be suitably modified. By summarizing the results of the analysis (Sect. 2) of the structure of the Decision and of the field investigation of a marble productive site (Sect. 3) previously presented, the following are here proposed:

- Indicator I4 should be properly modified, by taking into account the pollutant releases in the atmosphere of all the working activities.
- A new parameter (indicator I7) should be introduced to account for the amount of commercially utilizable blocks, extracted and addressed to sawmill, with respect to the total extracted material; this parameter can be assumed as a general measure for the efficiency of the marble production site.
- A new parameter (indicator I8) should be introduced to account for the relevant volume of materials disposed in landfills.
- A new parameter (indicator I9) should be finally introduced to account for the use of explosive in marble quarry.

As a result of these considerations regarding the criterion 1 and its sub-indicators, a new matrix of pertinent scores is here

Table 4 New matrix proposed to score the raw material extraction management in the case of marble

Indicator		Score				
		5 (Excellent)	3 (Good)	1 (Sufficient)	Threshold	Relative weights
I1 Water recycling ratio (%)		>80	80–70	69–65	<65	W3
I2 Quarry impact ratio (%)		<15	15–30	31–50	>50	W1, W2
I3 Natural resource appreciation (%)		**>60**	**60–45**	**44–35**	**<35**	–
I4 Air quality (μg/m^3)	PM_{10}	**<15**	**15–30**	**31–40**	**>40[a]**	W2
	NO_x	**<10**	**10–20**	**21–30**	**>30[a]**	**W2**
	$PM_{2.5}$	**<10**	**10–15**	**16–25**	**>25[a]**	**W2**
	SO_2	**<40**	**40–80**	**81–125**	**>125[b]**	**SO_2**
	CO (g/m^3)	**<3**	**3–6**	**7–10**	**>10[b]**	**W2**
I5 Water quality (mg/l)		<15	15–30	31–40	>40	W1, W2, W3
I6 Noise (dB(A))		<30	30–55	56–60	>60	W2
I7 Blocks recovery (%)		**>40**	**40–30**	**29–20**	**<20**	–
I8 Quarrywaste(%)		**<20**	**20–30**	**31–40**	**>40**	–
I9 Use of explosives (kg/m^3)		–	–	–	–	–

Note: all changes and/or integrations to the original matrix are reported in bold

[a] yearly limit; [b] daily limit

proposed (Table 4), where all changes and/or integrations to the original matrix are reported in the dashed boxes.

Benchmarks related to indicator I3 have been modified. In this case again, the proposed benchmarks are those included in the previous version of the Decision whose stricter values seem to better apply to sustainability criteria.

The benchmarks for pollutants (indicator I4) refer to yearly, daily, and warning values, as indicated in the Italian standard concerning this sector (D.lgs. 155 2010). This selection, obviously, depends on the law situation of the marble district of Custonaci. For a general use of the table, values referring to each pollutant should be those established by technical standards and regulations issued in the country where the productive site is located.

The benchmarks attributed to the new proposed indicators I7 and I8 (“blocks recovery” and “quarry waste”) have those referring to the previous release of the Decision, where an indicator accounting for the “block recovery” was actually present.

As regards indicator I9, at the present state, it must be observed that benchmarks referring to the amount of explosive utilized to destroy the superficial vegetation layer below which marble blocks are positioned cannot be attributed. In fact, a standard concerning limit values of explosive to be utilized in quarries does not exit so far. Currently, an “in-field” analysis is being carried out by the present authors in the Custonaci productive district, to collect data concerning the amount of explosive used and to identify average and, possibly, limit values. At the moment, the simple indication of the amount of explosive used (kg/m^3) could be required to firms, in order to be eligible for the Eco-label award.

With reference to indicator I4, a more accurate evaluation of the pollutant emissions produced by the extraction operations in quarry is proposed here. The considered additional emissions (direct impacts) are reported in Fig. 4, not only for firm A but also for another firm (here called “firm B”, again for privacy reasons), working in the Custonaci marble basin.

Although firm B differs slightly in the productive chain from firm A, it is similarly representative of the production practices of this marble district. Both show the same material flow distribution. Because such emissions are generated near the quarry, they can be calculated along the perimeter of the sites area, using a direct method, based on test methods present in the pertinent standards, that is UNI EN 12341 (2001) for PM_{10}, UNI EN 14791 (2006) for SO_2, UNI EN 14792 (2006) for NO_x, UNI EN 14907 (2005) for $PM_{2.5}$, and UNI EN 14626 (2005) for CO.

As observed from Fig. 4, although characterized by comparable mass flows in quarry, the two firms present different pollutant releases in the atmosphere (emissions of firm B are lower than the ones of firm A). This difference can be explained by considering the presence of a more advanced technological equipment in firm B. All these direct impacts are embodied in the new version of the I4 indicator proposed here.

Anyway, the productive chain of marble is also responsible of indirect emissions, of which firms are not directly accountable. In fact, as already mentioned (see Fig. 3), the electricity is contemplated among the energy sources used: in this case, clearly, pollutants are not emitted nearby the quarry but at the site of the thermal power plant that generates the electric energy. Obviously, as these emissions depend on the national mix of fuels by means of which the electric energy is generated, the pollutant emissions in this way produced cannot be attribute directly to the marble working firms.

Anyway, if a given firm would decide to install renewable sources plants for the in situ generation of electric energy, the mix of fuels generating the mean kilowatt per hour of electric energy used by the firm would be locally modified which means that a given quantity of saved emissions (and CO_2 among them) should somehow be recognized to the firm as a positive contribution to the environmental sustainability.

Should the impact of the electric energy be taken into account in the environmental balance of a marble firm, the local, and “far” generation of this energy source must be separately considered. For the electric energy delivered by the national network, the pertinent emissions can be only indirectly evaluated (Fig. 5) by means of the emission factors of each single energy source, which are usually available in literature (Ministero delle Attività Produttive 2002) for each

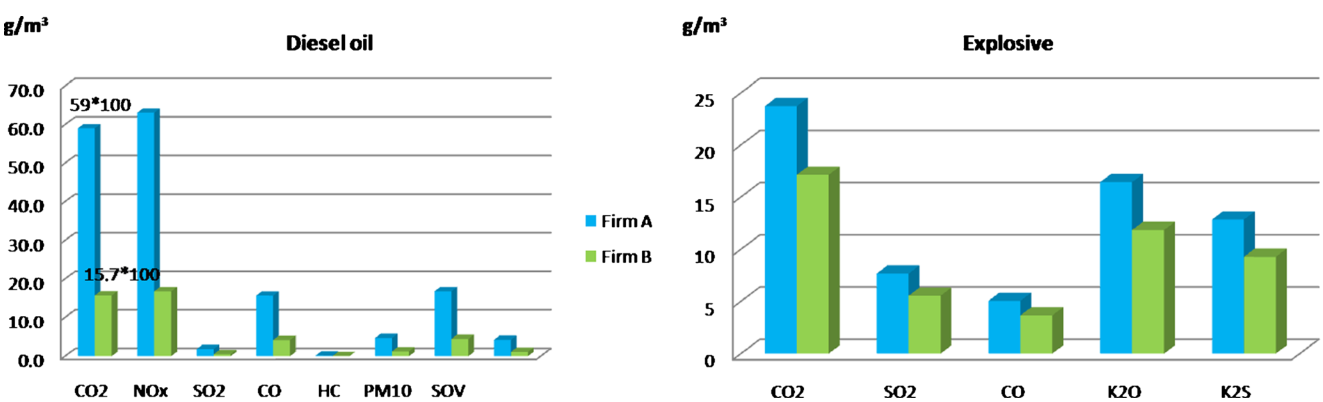


Fig. 4 Total emission in quarry for Firm A and Firm B for unitary volume of material

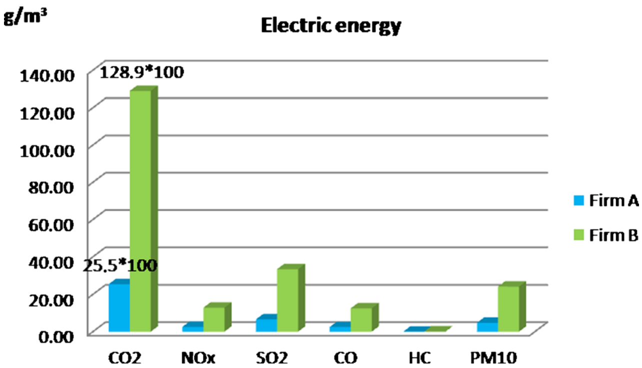


Fig. 5 Total emissions generated in to the production cycle of the electric energy used in Firms A and B

country. For example, in our application, firm B should be appointed with a higher environmental rank, since it utilizes a photovoltaic plant to generate part of the needed electric energy. This, in fact, determines a lower amount of pollutant emissions per functional unit of product.

The typical distribution of mass flows in quarry, in percentage values, valid for both firms is reported in Fig. 6. More specifically, the total extracted material *a* consists commercial blocks, *b* (this part accounts for 30 % of total extracted material), and by-products, *c* (this part accounts for 70 %); the latter is made, in turn, of disposal material, *d* (this part accounts for 30 %) and usable material, *e* (this part accounts for 70 %).

Starting from this distribution of mass flows, indicator I3 (already present in the Decision) and indicators I7 and I8 (here proposed) can be computed for firms A and B.

$$\mathrm{I3} = \frac{\text{commercial blocks} + \text{usable materials}}{\text{total extracted material}} = \frac{b+e}{a} \cong 30\%;$$

$$\mathrm{I7} = \frac{\text{commercial blocks}}{\text{total extracted material}} = \frac{b}{a} \cong 70\%;$$

$$\mathrm{I8} = \frac{\text{disposable material}}{\text{total extracted material}} = \frac{d}{a} \cong 21\%.$$

As regards indicator I9, it has been calculated for the two considered firms as ratio between the amount of used explosive and the amount of removed material. It resulted to be 0.07 kg/m^3 for firm A and 0.02 kg/m^3 for firm B.

According to the Decision 607/2009, as already mentioned in Sect. 2.1, quarries must obtain, with regard to criterion 1, a weighted score of at least 19 points to be eligible for the Ecolabel award. Based on the changes and new proposals regarding on the matrix, this weighted score cannot be confirmed so far. Tentatively, by considering that in the current matrix for each of six indicators a mean value of approximately 3 points is required, in this new proposed version of the matrix, composed by 9 indicators, a total score of 28 points could be reasonably proposed.

4.2 Criterion 2—Raw material selection

As regards *criterion 2* (“raw material selection”), no modifications are proposed here because relevant weaknesses did not emerge through the present analysis.

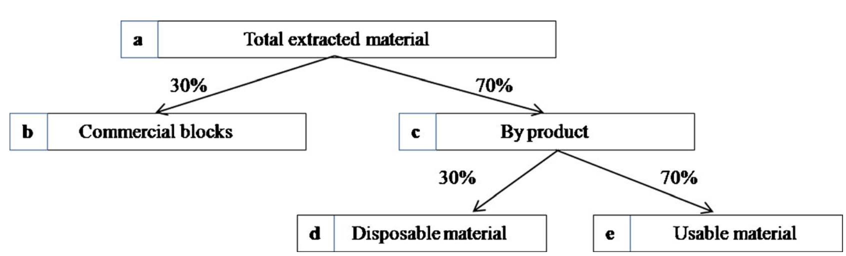
4.3 Criterion 3—Finishing operation

With respect to *criterion 3* (“finishing operation”), the environmental impacts generated by the finishing operations certainly need to be evaluated more accurately, and the energy consumption related to the use of the several different involved equipment must be accounted for. In fact, our application of an LCA analysis to the “Perlato di Sicilia” has shown that energy consumption related to the polishing and resin tapping operations accounts for as far as 30 % of the whole amount of energy utilized in sawmill. Therefore, the calculation of this energy consumption should be also included among the Decision parameters. This energy consumption could be usefully calculated, as suggested in the Decision, like “process energy requirement” (PER). Clearly, the threshold and the test method to be used have to be established as well. Ranges already present in criterion 4 (“Production process”) could be used with this purpose; they, in fact, even though refer to processed products, can be similarly applied in case of marble and natural stones. The PER limit, in this case, should not exceed the level of 1.6 MJ/kg.

4.4 Criterion 4—Production process

Actually, this criterion has not been treated in the previous analysis, since it refers only to processed products and not to natural products, as marble is. Anyway, some of the subcriteria included in it in the current version of the Decision

Fig. 6 Typical distribution of mass flows in quarry, in percentage terms, as result of the “in-field” analysis of both firms



could be considered for inclusion in a new release of the award scheme.

In fact, a criterion for air emissions, that takes into account all of the pollutant emissions generated during the manufacturing process of marble in sawmill, should be present in a scheme for natural stones and marble. Actually, in the Decision, a criterion (sub-criterion 4.3 in Table 1) referred to the working process is already present, but it is referred only to processed materials excluding all natural products like marble. Therefore, this criterion might be extended, with the due modifications, to natural products.

Moreover, since in the Decision, no indicators that take into account the possible use of renewable sources are present, a new parameter could be thus introduced to measure the pollutant emissions saved depending on the possible use of renewable sources.

4.5 Criterion 5—Waste management

As regards *criterion 5* (“waste management”), it should be properly modified to consider both the managing of waste derived from the manufacturing process of marble slabs and tiles and the recycling of by-product materials that, in this case, accounts for approximately 70 % of the treated product (Founti 2010). Again, such waste production should be suitably taken into account. Therefore, an extension to marble of sub-criterion 5.2 "waste recovery" (see Table 1) is suggested.

As regards the production of marble blocks that takes place in sawmill, a criterion accounting for the energy and resource consumption occurring in this phase along with its resultant impacts should also be introduced.

5 Conclusions

An Eco-label award for marble used in building sector clearly represents a strong commercial tool for communicating the sustainability performances of this important material, provided that the criteria utilized for awarding the firms are really capable of capturing all the impacts related to its productive chain. With this aim, in this work, a critical analysis of the current Decision concerning hard coverings has been preliminarily conducted to verify whether it is actually viable for the natural products, like marble. This verification highlighted some critical points of this Document when applied to marble.

Moreover, a field study has been performed, by examining the whole productive chain of a couple of firms treating the “Perlato di Sicilia” marble, which includes either the extraction and processing phases or finishing operations. The application of a classical LCA methodology, enabling the accounting for all of the emissions due to the production chain, was utilized in this aim.

The current version of the Decision seems to present some serious limitations when applied to marble and natural stones that have a productive chain similar to the marble one, such as granite (Mendoza et al. 2012; Mendoza et al. 2014) for example.

The analysis of the structure of the Decision and the field checking on two firms of the Custonaci marble district in Sicily has raised the following considerations:

(a) The introduction of new environmental indicators (I7, I8, and I9) referring to the criterion “raw material extraction” is suggested, in order to better describe the operations involved in this phase.
(b) As regards the criteria “raw material selection”, “finishing operation”, and “waste management”, a certain number of modifications, essentially concerning aspects that are typical of the marble working process and that were not properly indicated in the Decision, have been also proposed here.
(c) With respect to the criterion “production process”, its extension to natural products has been proposed, provided that suitable changes are introduced.
(d) The indication of the quantity of explosive utilized in quarry should be reported by firms that are candidate to apply for the excellence brand.
(e) The percentage of energy (electric as well thermal) produced by renewable sources should be included in the evaluation of the environmental performances of a given firm.

Clearly, further investigations are needed in order to better assess the proposed scheme, especially in terms of threshold values of pollutant releases and use of explosive that are actually specific for the marble productive chain. Moreover, additional analyses should be addressed to better particularize marble in the weighting factors W1, W2, and W3 applied in the quarry operations.

Despite these still open questions, the changes here introduced can represent a useful indication toward a more suitable scheme of the EU Eco-label for marble, at least. In fact, the present modified version of the standard has been proposed to the Sicilian administration in order to be voluntarily adopted by marble productive sites of the region, in the aim of extensively verifying its suitability.

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